International Journal of Water Resources and Arid Environments 9(1): 80-86, 2020
ISSN 2079-7079

Using Topographic and Geographic Terrain Characteristics for Mapping Annual Rainfall in the Tafna Watershed, Western Algeria

Zaagane Mansour, Hamimed Abderahmane and Refas Soraya

Research Laboratory of Biological Systems and Geomatics (LRSBG),
Mascara University, Box 305 Mamounia road, Mascara 29000, Algeria

Abstract: Conventional methods of precipitation mapping give way to computer-assisted mapping. The computing resources and tools currently available allow the processing of large amounts of observational data and their representation in an objective and rapid manner. Recent research shows its feasibility both in a particular year and in a any month of a given year. The maps produced form the basis of information grids ready to be used in Geographic Information Systems (GIS). They are indispensable for a continuously updated knowledge of the climate and the water resource. In this work, based on monthly data from 35 pluviometric stations in the Tafna watershed, it is proposed to examine the main changes that have affected rainfall patterns. To this end, a scientific approach has been adopted based essentially on the use of multiple regressions while integrating with the measured rainfall explanatory factors (altitude, aspect, distance from the sea and distance West/East). Indeed, this technique allowed us to focus on the influence of these factors cited in spatial distribution of rainfall. Although the most watered areas are located in the mountainous region, the rainfall values decrease while moving towards the plains whose altitudes are falling more and more.

Key words: Annual rainfall · Mapping · Topographic features · Geographic characteristics · Tafna watershed · Western Algeria

INTRODUCTION

The distribution and variability of rainfall conditioned the water management. The variability of inflows as rain impact many activities in Algeria, primarily agricultural production which cannot even feed the rural population [1]. Cereal crops and orchards, dominant in Algeria, requires large amounts of water. Rationing water and electricity has become the rule in bad years; all human activities are disrupted [2]. The estimation of average rainfall in a watershed is the preliminary work to any study of rainfall-runoff relationships [3]. The calculation of the other terms of the hydrological balance depends on the accuracy of the rainfall estimate: interception, evapotranspiration and infiltration [4]. The data only obtained from rainfall stations are not always sufficient because the spatial distribution of precipitation is most often related to the topography because the spatial distribution of precipitation is most often related to the topography (elevation and aspect), to the morphometric parameters of the environment and to the position on the continental surfaces (distance from the sea) [4]. For this purpose, conventional methods of interpolation between stations which do not take into account orographic effects are not suitable to regions where the terrain is very rugged [4]. Sometimes simple and quick to apply (Thiessen polygons, for example), these methods can give satisfactory results when used on the large watersheds basis where rainfall stations are numerous and homogeneously distributed [5].

With advances in remote sensing and geographic information systems (GIS) technologies, improved characterizations of topography for precipitation mapping can be performed. Quantified values of these characteristics can be used as explanatory variables in the interpolation of precipitation [6]. The method presented in this work uses multiple linear regressions (MLR) to interpolate precipitation onto a gridded surface. An MLR equation is determined using measured annual precipitation as the dependent variable and location (distance from sea, distance west-east) and DEM derived measures (elevation and aspect) as explanatory variables.

Corresponding Author: Zaagane Mansour, Research laboratory of biological systems and geomatics (LRSBG), Mascara University, Box 305 Mamounia road, Mascara 29000, Algeria. E-mail: zaagane@yahoo.fr.

The same explanatory variables are then derived for a 100 x 100 km gridded surface in the large watershed of Tafna in western Algeria and used with the MLR equations to estimate precipitation on that gridded surface.

MATERIEL AND METHODS

Study Area: The river Tafna is characterized by a length of 228 Km (Fig. 1). Its watershed, located in northwestern Algeria, covers an area of 7254 km^2. It consists of eight sub-basins; two are located upstream in Morocco. This Moroccan part represents an area of 2 007 km^2, corresponding to 27.7% of the total area. For lack of information on the region located in Moroccan territory, our work only focuses on the Algerian part. The watershed Tafna is characterized by a very rugged terrain, with an average altitude of 780 m and a maximum altitude exceeding 1800 m [7].

The relief is a critical factor in the hydrological behavior of a watershed because it largely determines the ability of land runoff, infiltration and evaporation. For the Tafna watershed, the relief layout and the abundance of impervious rocks combined their effects to create a dense drainage system, with drainage densities (quotients of the sum of the lengths of all streams to the drainage basin area) ranging from 0.5 to 2.9 depending on the size of the sub-basins [7].

Choice of Stations and Period of Study: The study of the climate monitoring its evolution requires long and numerous series of observations. Unfortunately, we do not have perfectly reliable or continuous data series.

Rainfall data of the Tafna watershed were provided by the National Water Resources Agency (ANRH). These available rainfall data are very heterogeneous, both from the point of view of the measurements reliability and the observation duration of the series. The earliest observations date since 1873.

The series of climate data often contain errors that can have multiple origins (read error, error report, derating of the equipment, etc.).

We can distinguish accidental errors which are randomly distributed in time and space, and systematic errors that affect a continuously portions of the measurement series, randomly distributed in time and space.

During the processing of the data, some values appear to be unusual compared to the rest of the time series. The existence of outliers can lead climatologist for misinterpretation. It is therefore essential to compare all stations records belonging to the same micro-region to ensure they do not exhibit abnormal discrepancy. For example, in 1974, at the station of Beni Bahdel, the annual total rainfall is particularly singular (1229.7 mm),

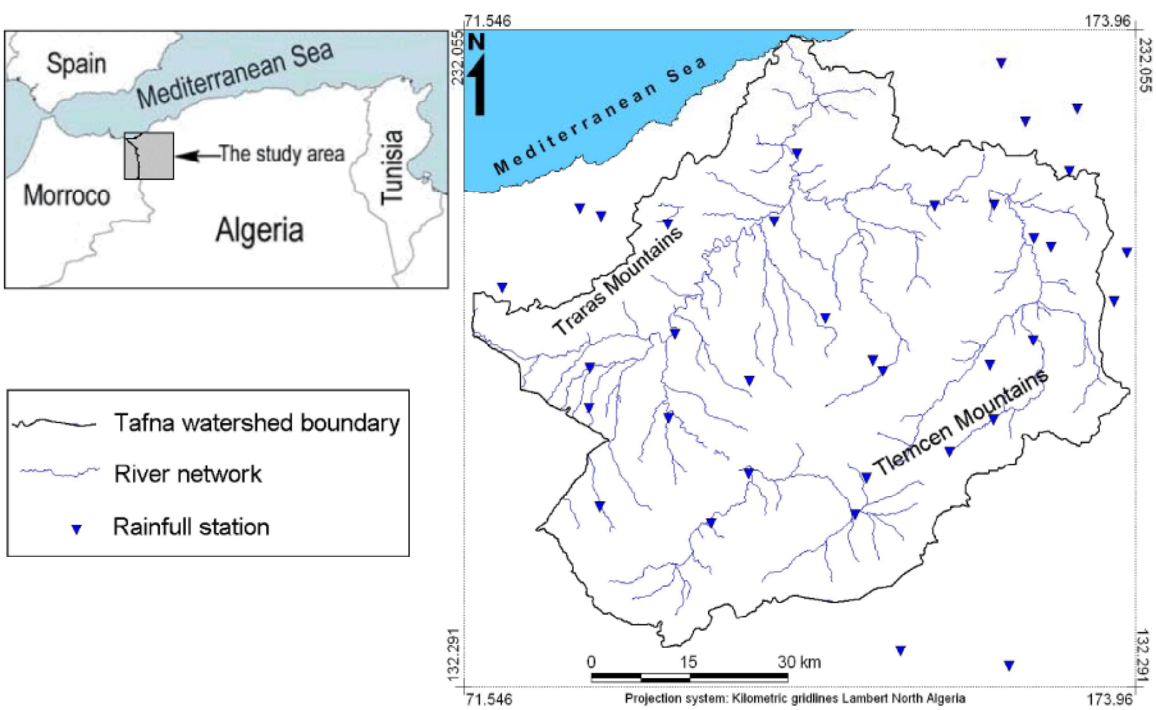

Fig. 1: location of the study area

comparing it with other neighboring stations (Chouly: 194.5 mm, Mefrouche: 273.4 mm), we deduce that this value is an outlier [8].

We have tried to identify a maximum of measuring stations meeting the following conditions: (i) information covering the last four decades, (ii) no gaps of more than five consecutive years, (iii) less than 10% of gaps in the total series on a monthly scale.

For the study purposes and for good spatial distribution, we proceeded to filling gaps using simple linear regression.

For this study, 35 stations were selected over 41 hydrological years from 1970 -2011 including 24 stations distributed in the basin (Fig. 1). For a reliable interpolation of annual rainfall in the studied watershed, we used data from 11 stations in neighboring basins.

The stations are relatively well distributed throughout the studied basin. An extremely tight network of measuring points would, by their only altitude, accurately reflect the topography.

The statistical analysis of the annual rainfall series was performed on precipitation totals for the year, which starts on September 1st of year k and ends on August 31st of year k+1.

Methodology: There is clearly a strong relationship between relief and the spatial distribution of rainfall. The approach proposed in this work aims to map the statistical parameters of precipitation by valuing all available information, including topographic information [9]. The idea is very simple since it consists in saying that the rainfall parameters can be explained in large part by perfectly known geographic factors (spatial position, altitude, aspect, station site, distance from the sea ...).

Only the part of the variance of rain, unexplained by these parameters, therefore deserves to be interpolated by spatial analysis techniques such as kriging.

To highlight this influence of the relief, the cartography of the precipitations was established by kriging taking into account the relief. The relief is taken into account from a Digital Elevation Model (DEM) with a mesh of 500 m resolution, which is largely sufficient for a general rainfall study and to smooth the altitude values for reduce the effect of landscape roughness [10]. It has been assumed that the mean annual rainfall (Pm) at any point in the territory is a linear function combining the four explanatory components, namely the altitude of point (Z), its aspects (E), its distance from the sea (D) and its longitude (X).

This linear function is obtained by analyzing the multiple regressions between the observed annual rainfall and the explanatory components.

$$Pm = a_1 \times Z + a_2 \times E + a_3 \times D + a_4 \times X + b$$

where a_1, a_2, a_3, a_4 and b are the five coefficients that consist in minimizing the square of the differences between the observed and the estimated rainfall with values of 20 and 25.

Rainfall at one point of land therefore depends on a regional component and a local component. The local component integrates the influence of the relief as well as that of the position of this point. It is well known that two sites whose morphometric context is similar do not receive the same amount of rainfall according to their position relative to the air masses: it will rain more on the site exposed to humid winds than on the second site placed "under the wind"(this positioning effect in the" downwind "is taken into account by the aspects of the slopes). Hence, the interest of integrating the geographical coordinates X (west-east distance) of any point of the territory, the relief (elevation and aspect) and the distance to the sea [11], [12]. The linear multiple regression using observed rainfall data and topographic and geographic characteristics allows getting the following equation:

$$Pm = 0.3734 \times Z - 0.1 \times E - 4.862 \times D + 1.483 \times X + 181.97$$

The application of this equation allows mapping the estimated annual rainfall (Fig. 2).

In the case of all of Northern Algeria, there is a negative relationship between rainfall and the distance of stations from the sea, which results in a decrease in rainfall more than one moves away from the coast.

The grid of the distance to the sea (coast line) is obtained by interpolating polylines drawn parallel to an interval of 20 km at the coast line. This approach was also adopted for the realization of the West-East remoteness grid.

The characteristic parameters of each station were calculated by the software surfer. A selection of the most explanatory parameters of the "rainfall" phenomenon was made in a first step as described above. All data processing was done using the software (Excel) and this in order to minimize the square of the differences between the observed rains and the estimated rains. This difference is called "Residue" (Residue = Observed (mm) - Estimated (mm)) and it is shown in Figure 3.

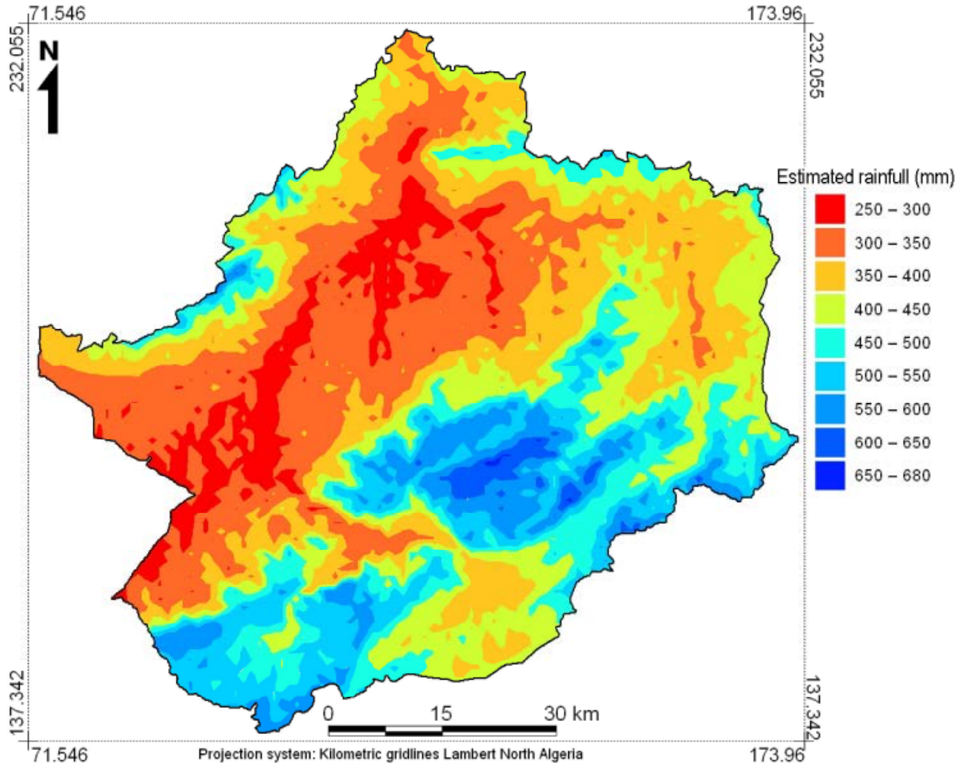

Fig. 2: Estimated rainfall according to the proposed model.

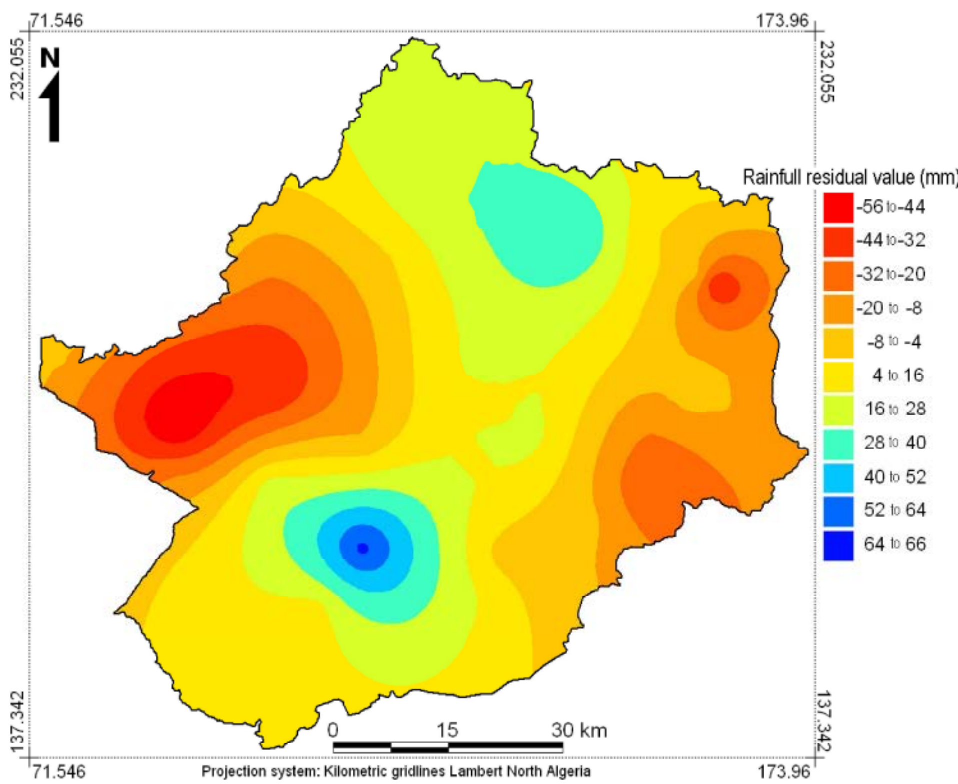

Fig. 3: The map of residues

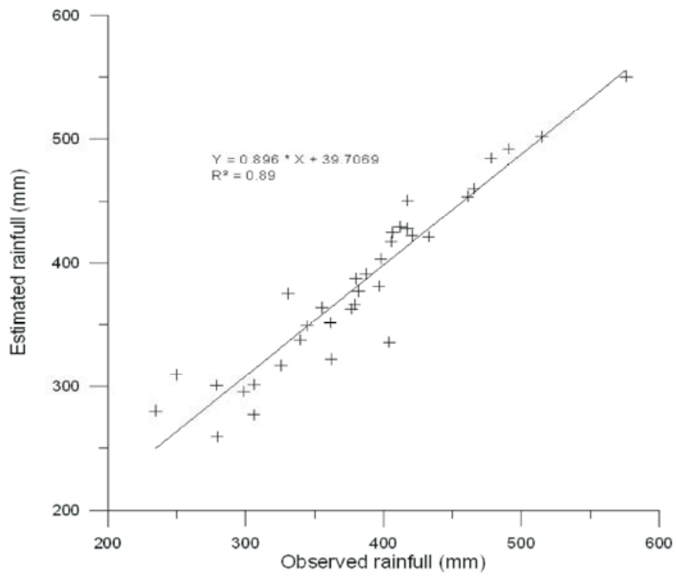

Fig. 4: Linear regression between observed (actual) rainfall and estimated rainfall.

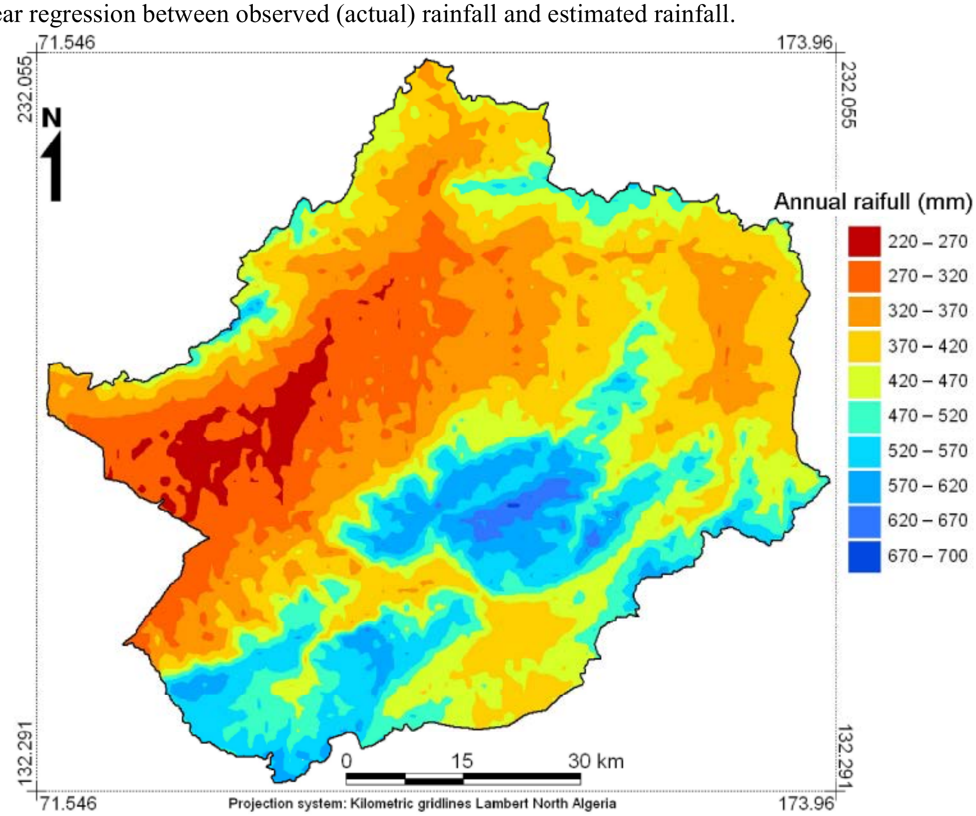

Fig. 5: The map of annual mean rainfall (mm)

Figure 3 shows the quality of the estimate obtained by the model applied to the rainfall observed data.

The final precipitation grid is only the sum of two grids (Fig. 5); the first corresponds to estimated rainfall and the second relates to residues that are interpolated by kriging.

Indeed, and in order to obtain the final grids to be mapped, it is necessary to add to the calculated rains the regression residues. These residues are stationary, ie they are zero on average and of constant variance. These residues therefore lend themselves more easily to interpolation [9].

These residues correspond to a part of the rains not explained directly by the relief but whose exact meaning remains nevertheless complex [13, 14]. To add these residues to calculated rainfall, they are regionalized with interpolation using a kriging algorithm. In this way, we obtain for each node of the DEM a value of the residues which allow the correction of the calculated precipitations and thus to optimize the final result on the whole of the zone studied. In order to show the desirability of the regionalization of the residues, we went through a variographic analysis of the residues.

RESULTS AND DISCUSSION

The spatial distribution map of mean rainfall in the Tafna watershed represents a typical feature in western Algeria. Indeed, there is a clear pluviometric decrease from north to south.

There is also a significant rainfall decrease from West to East; the difference becomes more and more important as we be near the Tlemcen Mountains.

The Tafna watershed has a number of distinct rain zones. To the north appears a relatively homogeneous rainfall zone between 450- 650 which corresponds to the plains and the littoral massifs (Traras mountain) these receive the rains bring by the humid winds NW-SE (Fig. 5).

Values are becoming weaker in the central part of the Tafna watershed. Indeed, these inner plains correspond to basins structured between a corridor of mountain ranges (Tlemcen Mountains in the south and those of Traras in the North) (Fig. 5).

The partitions of reliefs lead to a set of depressions which introduce the marked variations of the rainfall independently of the altitude or the distance to the sea.

Rainfall decreases rapidly as we move to the south; by crossing the mountainous barrier, the winds lose a large part of their humidity, the air compresses in its descent movement and heats up, so it dries (Foehn effect): less than 450 mm are recorded in the plain of the Tafna where the shelter effect is particularly accentuated in the south of the Tratas mountains.

A clear decrease in rainfall is also to be reported as one goes to the south, but the gradient is less strong. Here the topography is lowered and the role of latitude, comparatively, is more felt; we go more than 450 mm a year on the central part more than 650 mm, in the extreme south of the Tafna watershed.

CONCLUSION

The annual mean rainfall study of the Tafna watershed highlighted the predominant role of relief in the spatial distribution of precipitation.

The rainfall map is largely modeled on the relief map, but the role of the other geographical factors (longitude, distance from the sea and exposure) is included.

The use of a digital terrain model (DTM) for the first time has allowed for the correcting of some isohyets in underserved areas at measurement stations. However, the lack of data in these areas did not allow a quantitative evaluation of these predictions. This method made it possible to concretize the presence of rainfall nuclei of more than 700 mm, which remained until then theoretical, in particular on the mountains of Tlemcen.

This result explains largely the presence of a highly developed karstic system knowing that the skeleton of these mountains are Jurassic limestones.

In the distribution of rainfall, local nuances related to exposure have been found, particularly in the southern part of the Tlemcen Mountains and on the southern facade of the littoral massifs (Traras mountains).

This mapping of annual average rainfall presents some imperfections mainly related to the deficiencies of the observation network and the data gaps. As a result, the renovation of this network, but especially its extension in the mountainous regions is much desired.

REFERENCE

1. Etzold, B., A.U. Ahmed, Hassan, S.R. Neelormi and T. Afifi, 2016. Rainfall Variability, Hunger, and Social Inequality, and Their Relative Influences on Migration: Evidence from Bangladesh. In Environmental Migration and Social Inequality, pp: 27-41). Springer, Cham.
2. Koehler, J., S. Rayner, J. Katuva, P. Thomson and R. Hope, 2018. A cultural theory of drinking water risks, values and institutional change. Global Environmental Change, 50: 268-277.
3. Reitz, M., W.E. Sanford, G.B. Senay and J. Cazenas, 2017. Annual Estimates of Recharge, Quick-Flow Runoff, and Evapotranspiration for the Contiguous US Using Empirical Regression Equations. JAWRA Journal of the American Water Resources Association, 53(4): 961-983.

4. Shen, X. and E.N. Anagnostou, 2017. A framework to improve hyper-resolution hydrological simulation in snow-affected regions. Journal of hydrology, 552: 1-12.
5. Pluntke, T., N. Jatho, C. Kurbjuhn, J. Dietrich and C. Bernhofer, 2010. Use of past precipitation data for regionalisation of hourly rainfall in the low mountain ranges of Saxony, Germany. Natural Hazards and Earth System Sciences, 10(2): 353.
6. Hay, L., R. Viger and McCABE, Gregory, 1998. Precipitation interpolation in mountainous regions using multiple linear regression. IAHS Publications-Series of Proceedings and Reports-Intern Assoc Hydrological Sciences, 248: 33-38.
7. Ketrouci, K., M. Meddi and B. Abdesselam, 2012. Étude des crues extrêmes en Algérie: cas du bassin-versant de la Tafna. Science et changements planétaires/Sécheresse, 23(4): 297-305.
8. Meddi, M. and P. Hubert, 2003. Impact de la modification du régime pluviométrique sur les ressources en eau du Nord-Ouest de l'Algérie. IAHS Publication, 229-235.
9. Laborde, J.P., 1995. Les différentes étapes d'une cartographie automatique: exemple de la carte pluviométrique de l'Algérie du Nord. Publications de l'Association Internationale de Climatologie, 8: 37-46.
10. Traboulsi, M.M., 2010. La pluviométrie moyenne annuelle au Liban, interpolation et cartographie automatique. Lebanese Science Journal, 11(2): 11.
11. Davtian, G., 1998. Analyse des données et cartographie automatique: application aux principales variables climatiques du versant méditerranéen du Maghreb (Doctoral dissertation, Nice), pp: 423.
12. Rhea, J.O., 1977. Orographic precipitation model for hydrometeorological use. Atmospheric Science Paper; pp: 287.
13. Dumas, D., 1998. Karsts du Zagros (Iran): Bilans hydrologiques et évolution géomorphologique (Doctoral dissertation, Strasbourg 1).
14. Edwards, K.A., G.A. Classen and E.H.J. Schroten, 1983. The water resource in tropical Africa and its exploitation.